GENERAL ELECTRIC

Proposal for

CO-OPERATIVE 345-KV DESIGN STUDIES

ELECTRIC UTILITY ENGINEERING

Proposal for

CO-OPERATIVE 345-KV DESIGN STUDIES

COMMONWEALTH EDISON COMPANY

GENERAL ELECTRIC

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Introduction

This proposal outlines a co-operative engineering program for the purpose of bringing to bear the technical data from Project EHV and related analytical studies to the electrical design of the Commonwealth Edison 345-kv transmission system which will connect the proposed down-state mine-mouth plant at Kincaid to 345-kv bulk power load centers in the Chicago area. Subsequent paragraphs of this proposal list specific areas of study, most of which were discussed in detail at an engineering meeting held April 20, 1962. However, the intent of the proposal is to make available to Commonwealth Edison all data relating to the design of extra-high-voltage a-c systems available within General Electric. While most of the solution techniques have been applied to advantage in other line-design studies, others require the close co-operation of an operating utility in order to be reduced to a form readily applicable to design problems.

To assure that Commonwealth Edison engineering personnel share completely in the technical knowledge resulting from these and previous EHV studies, it is suggested that one or two engineers be assigned to work with engineers at Project EHV and in Electric Utility Engineering Operation on all phases of the program. General Electric will supply additional personnel and computer time necessary for completion of the studies in ample time for inclusion of their results in Commonwealth Edison's design of the mine-mouth transmission system.

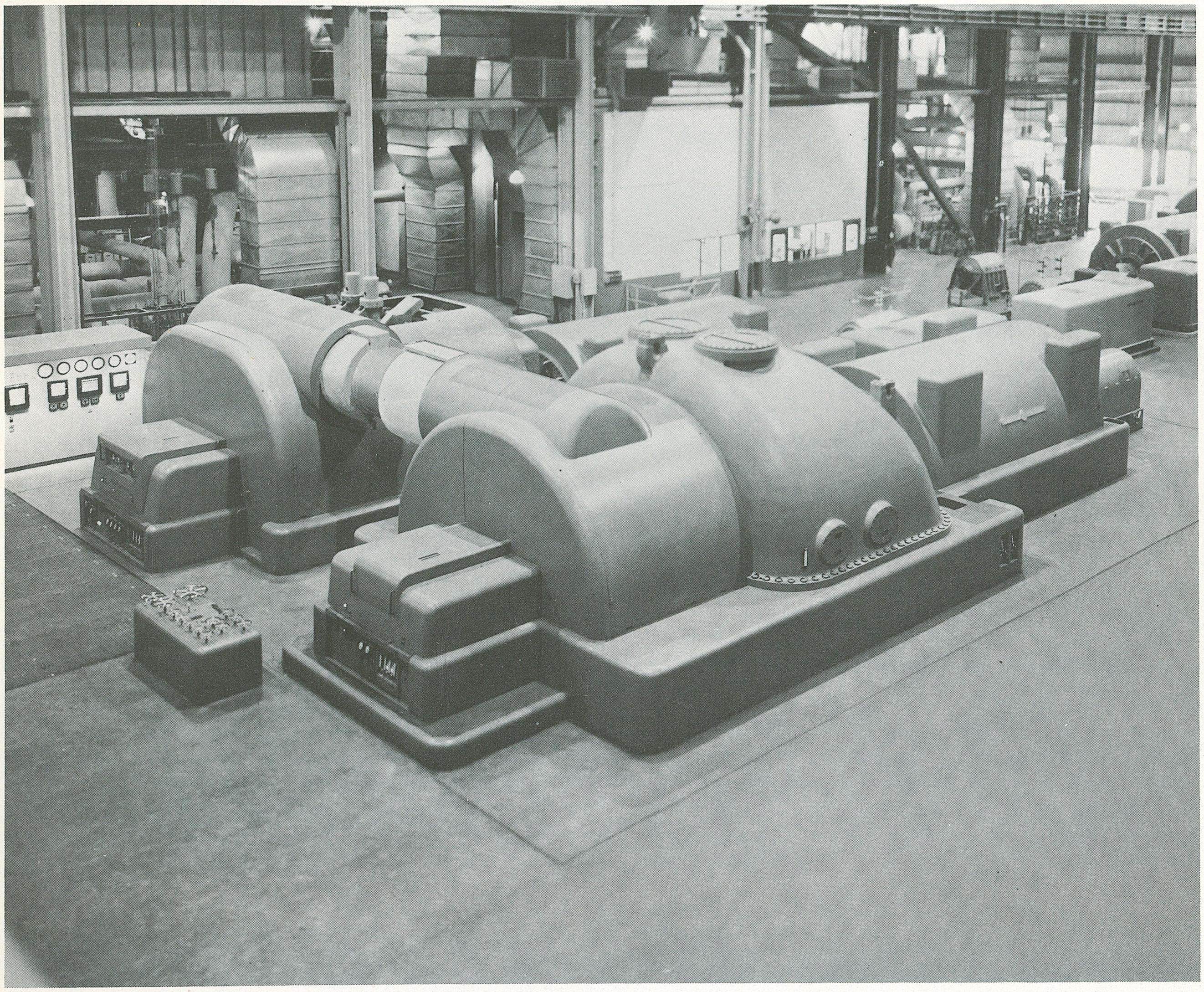
Suggested Scope of Participation:

Commonwealth Edison Company

1. One or two engineers, assigned to work with Project EHV engineers on all phases of the program.
2. Furnish and erect full-scale tower (as described in Section III) at Project EHV.

General Electric Company

1. Application engineering personnel from Electric Utility Engineering Operation and Project EHV necessary to apply results of Project EHV research specifically to Commonwealth Edison's 345-kv system design.
2. Computer time necessary to find solutions in the problem areas described.



Accurate transient analysis determines effect of transmission faults on system stability.

1. System Stability Studies

Nature of the Problem

As is the case with most moderate to long distance transmission systems, the optimum economic design of the 200 mile, 345-kv Kincaid mine-mouth transmission system is concerned largely with steady state and transient stability considerations.

Because of the extended time representation required for complete solution-- this is particularly true in testing for steady state stability-- it is important that accurate representation of governors, excitation systems and system load characteristics under varying conditions be included in the solution to assure accurate assessment of stability considerations.

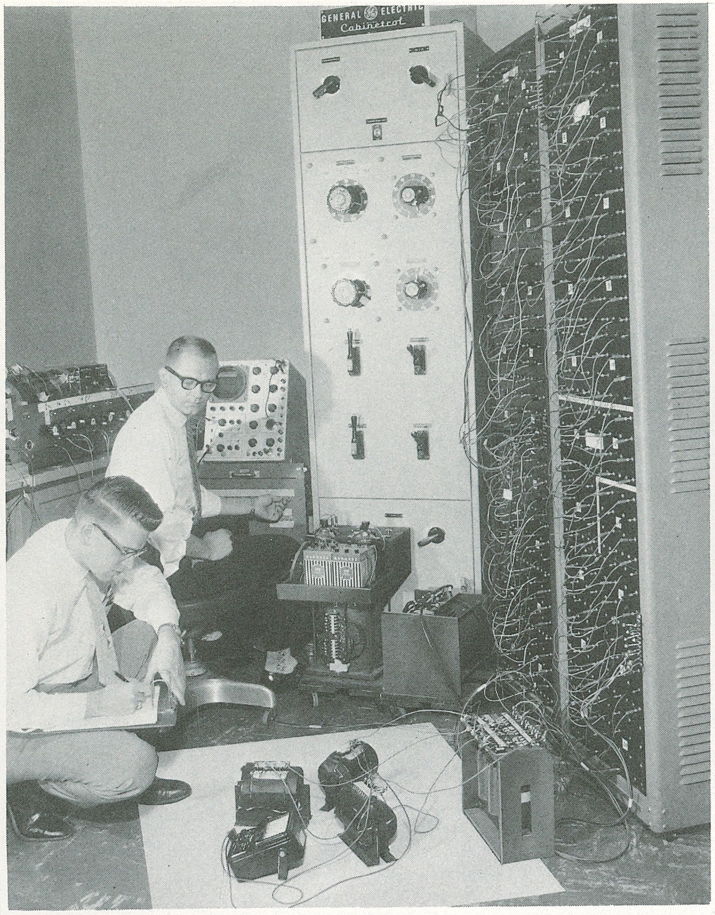
Methods of Solution

Load flow and stability studies--steady state and transient--will be performed in Schenectady using the latest programs that have been developed for the IBM 7090 computer. These programs --as Commonwealth Edison is aware--are capable of refined representation of excitation systems, governors and load characteristics. Methods are also available for representing series capacitor bypass switching and dynamic braking.

Objectives of Commonwealth Edison Studies

The broad objective of these studies will be to determine the optimum mine-mouth transmission design that will assure stable operation over the full range of expected system operating conditions. Parameters to be investigated could include:

1. Kincaid turbine-generator unit size.
2. The amount of series capacitor line compensation and switching arrangement at the intermediate switching station.
3. Size of dynamic braking resistor bank.
4. Switching arrangements at 345 kv load terminals.
5. Transformer reactance.
6. System relaying and line reclosing procedure.
7. Generator characteristics including short-circuit ratio and excitation system response.
8. Transmission line conductoring—single, dual and multi-conductor arrangements.
9. The amount and type of kilovar support at the receiving terminals.



Transient network analyzer determines system overvoltages.

II. Transient Voltage Study

Nature of the Problem:
In any new EHV undertaking, the possibility of damage to equipment and interruption of service through overvoltages caused by switching operations must be analyzed. In many cases switching surges are effectively limited by arrester operation. From the standpoint of transformer protection the principal problem is one of defining the rating of the lightning arrester to be applied. This, in turn, determines the BIL which can safely be used.

The insulation system on 345-kv lines finds its limiting condition in switching surge strength. Modern philosophy on line insulation often results in switching surge strength considerably lower than the level that could be protected by presently available arresters. In this case it is important, from a line design standpoint, to assess the switching voltages produced by all realistic switching or light-load operating conditions.

Methods of Solution:
Switching transients may be very effectively studied on the transient network analyzer.

The transient analyzer is an analog computer on which the system to be studied is set up in miniature, accurately representing the characteristics of transformers, line, and circuit breakers as to saturation, magnetizing reactance, line reactance and charging capacitance, variations in contact time of the three poles of a breaker, and other system and apparatus parameters.

Certain types of surge problems, notably those dealing with lightning arrester separation from protected apparatus and circuit breaker recovery voltage, are amenable to solution on a newly completed digital computer program. This program is in the process of extension to allow solution of a broader range of surge problems.

Objectives of Commonwealth Edison Studies

The objectives of the proposed study may be broadly stated as the definition of overvoltage duty for which the Commonwealth 345-kv mine-mouth transmission system and its component apparatus must be designed. Emphasis will be on the initial 345-kv link, though the ultimate system will be represented by either complete modeling or a valid equivalent.

The transient network analyzer studies would consist of a review of recent studies on similar systems (American Electric Power, Arizona Public Service, Ontario Hydro, and others) to confirm the relevance of their results, plus some specific extensions of these studies. In particular, the objectives seen at present are:

1. Study switching surges on line energization including the effect of two-step closing. The initial transient analyzer study would define maximum switching surge levels plus some approximate data on statistical distribution. A subsequent study may be required to define the statistical distribution more exactly.
2. Study of the possibility of transfer of surges from the 138-kv system with existing 138-kv breaker characteristics. Include the effects of multiple restrikes.
3. Confirmation that no-load conditions will be within tolerable bounds, including the effect of transformer saturation.
4. Define the lightning arrester discharge duty for the proposed system.
5. Study the advisability of furnishing tertiaries on the terminal 345-138 kv transformers.
6. Examine other surge conditions or apparatus duty suggested by the above studies.

Interrelation with Other Studies

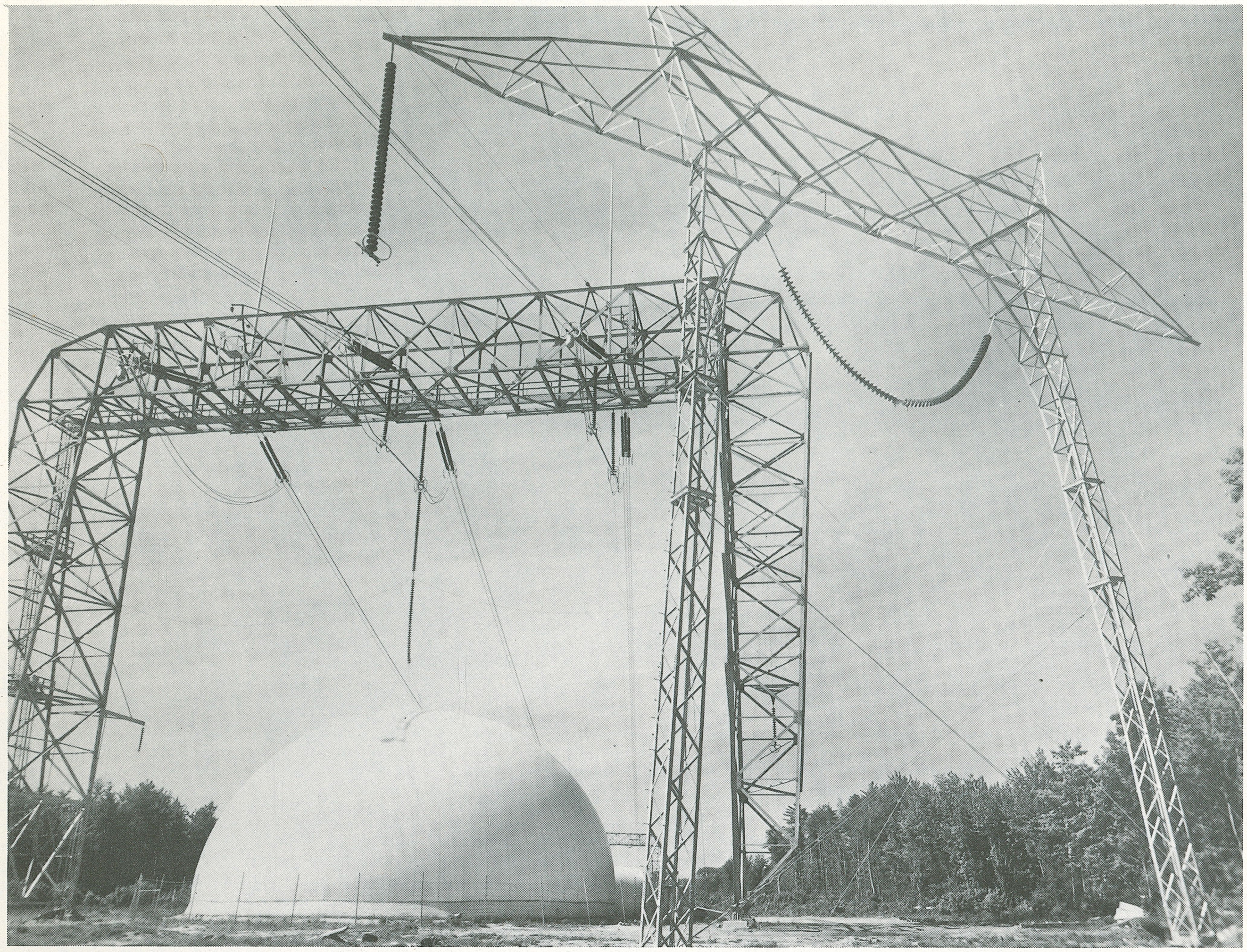
The transient voltage study is scheduled early on the agenda since it affords the following:

1. A basis of defining apparatus BIL's, use of tertiaries, the optimum size and the location of shunt reactors.
2. Provide data for the electrical design of towers. Switching surge studies plus some existing tower design data will permit a "trial design" for full-scale tests.
3. Statistical insulation planning studies can proceed with statistical switching surge data afforded by transient analyzer studies. Initial statistical approximations will permit a clearer definition of the problem and will point out which distributions required more exact study.

Timing

The initial transient network analyzer study can be scheduled for late 1962. This would be a two-week study with the expectation that another such study would be scheduled early in 1963 to pursue in greater detail problems felt most critical after initial studies.

Digital transient studies on single-phase equivalents will be available at any time on short notice. The three-phase digital program will be completed early in 1963, permitting additional studies at that time.



Full-scale tower, subjected to flashover tests, guides ultimate tower design.

III. Electrical Design of Towers

Nature of the Problem

Recent investigations on Project EHV have shown a serious discrepancy between flashover values measured on long insulator strings in the laboratory as compared with results measured on the same string when installed on a tower. It has been shown that tests on EHV insulator strings should be made in place, on the tower with which they are planned for use.

In addition to the detrimental effect of tower proximity in the strength of suspension insulator assemblies, some of the correction factors applying to ambient conditions have been found to differ from those traditionally used.

Methods of Solution

Although some very general relationships have evolved from prior work in this area, the present state of the art suggests that designs be tested full-scale and adjusted during the test program to assure adequate total strength and co-ordination between insulator strength and the strength of air gaps between the tower and the phase conductors. Successful design studies of this sort have been performed.

By mid-1963 it is likely that a relatively good basis for preliminary design for the Commonwealth Edison towers will be obtained. At that time an actual prototype can be tested for final electrical strength tests.

Objectives of Commonwealth Edison Studies

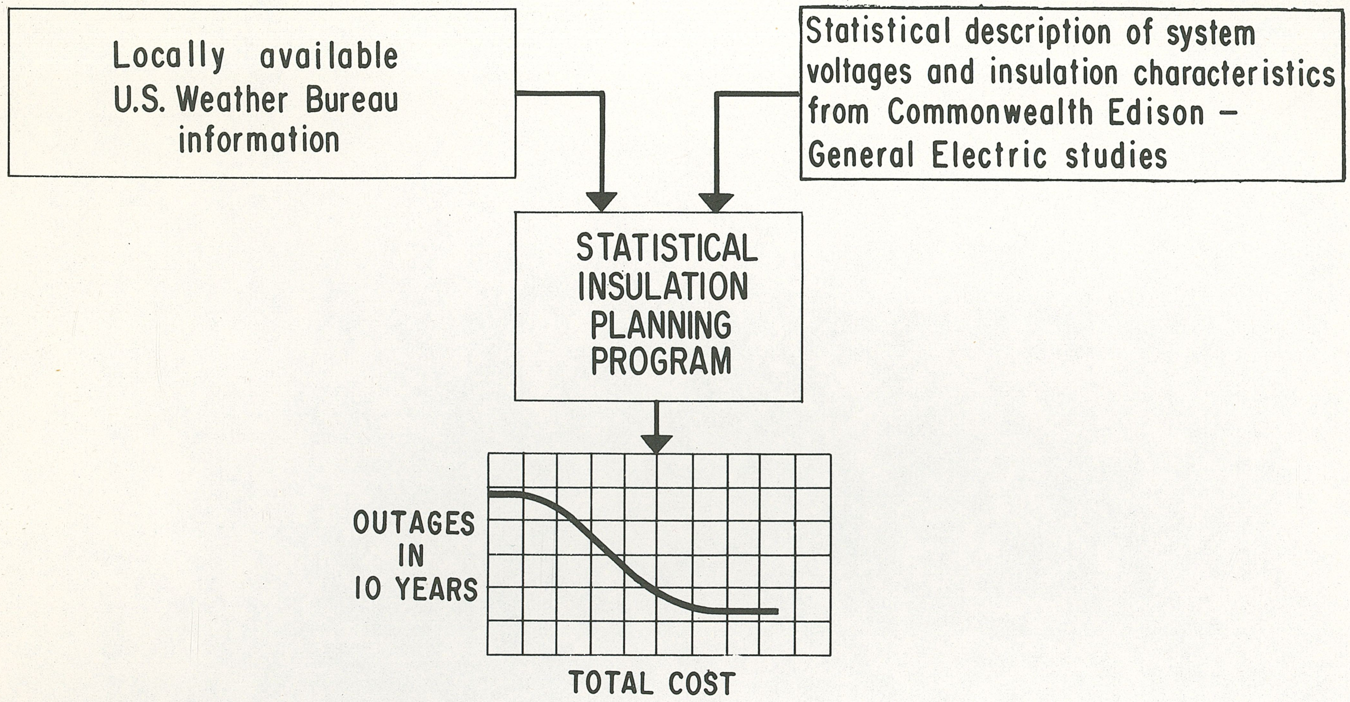
Preliminary work will consist of evaluating the electrical strength requirements of the Commonwealth Edison towers and reviewing tests performed for others as a basis for arriving at a specific tower design. This tower will then be erected at Project EHV and tested for switching surge strength in fair weather and during rain.

Interrelation with Other Studies

The wet switching surge withstand strength requirements of the tower insulation will be determined, in part, from transient network analyzer tests which simulate switching conditions on the future system. Statistical insulation planning studies will supplement transient analyzer tests by evaluating all of the pertinent statistical variables to forecast the total outage performance of alternative levels of line insulation strength.

Timing

Study of preliminary tower design ideas should begin immediately following the first transient network analyzer test program and extend through mid-1963. A final design full-scale tower could be erected for comprehensive testing in late 1963.


Locally available U.S. Weather Bureau information
Statistical description of system voltages and insulation characteristics from Commonwealth Edison – General Electric studies
STATISTICAL INSULATION PLANNING PROGRAM
OUTAGES IN 10 YEARS
TOTAL COST

Statistical analyses optimize insulation investment.

IV. Statistical Insulation Planning

Nature of the Problem:
Traditional methods of designing and specifying the insulation of transmission lines and terminal apparatus have been based on the maximum electrical stress anticipated in service. This philosophy continues to be justified in those cases where insulation failure may be considered catastrophic, e.g., transformer insulation. On some portions of the system insulation system, notably on the transmission line, insulation failure is not at all catastrophic and may therefore be interpreted with statistical methods. Rather than designing for maxima, it is advantageous to consider each variable in its true statistical nature (wind velocity, precipitation, switching surge magnitude, etc.) and combine them so as to yield an over-all outage rate for various design alternatives.

Methods of Solution:
A digital computer program has been completed which takes each of the statistical variables affecting a problem and, considering the cross-restraints these variables place on one another, predicts the total performance history of the composite system in terms of failures per year. The combined solution can include a number of insulation subsystems, e.g., the center phase insulation of a line, the outside phase insulation of a line, bus insulation, apparatus insulation, etc. The program is supplemented by an auxiliary program which relates the anticipated weather history in the geographic area of concern to the problem being studied. In the case of the insulation planning studies, a composite statistical frequency of insulation withstand strength would be developed by the auxiliary

program for each of the insulation subsystems being studied.

Objectives of Commonwealth Edison Studies

Both the scope of these studies and the nature of the cost information used in them would have to be the subject of cooperative discussions between Commonwealth Edison and the General Electric Company. The initial studies would include the insulation systems (center phase and outer phase) of the transmission line plus several items of station insulation and/or apparatus. The primary objective of this program would be to appraise the electrical design of the Commonwealth 345-kv line and station insulation systems to find the most economical design that is acceptable from an outage standpoint, with full evaluation of all of the statistical factors involved.

Interrelation with Other Studies

This work would be closely related to the full-scale testing of the Commonwealth 345-kv towers inasmuch as the insulation strength of these towers would be a major input to the program. The frequency distribution of switching surges would also be an important input to the statistical planning study. Preliminary estimates of both of the foregoing variables would be sufficient for preliminary studies that would serve to clarify the importance of each of the input quantities and establish some preliminary estimates of the design optimums.

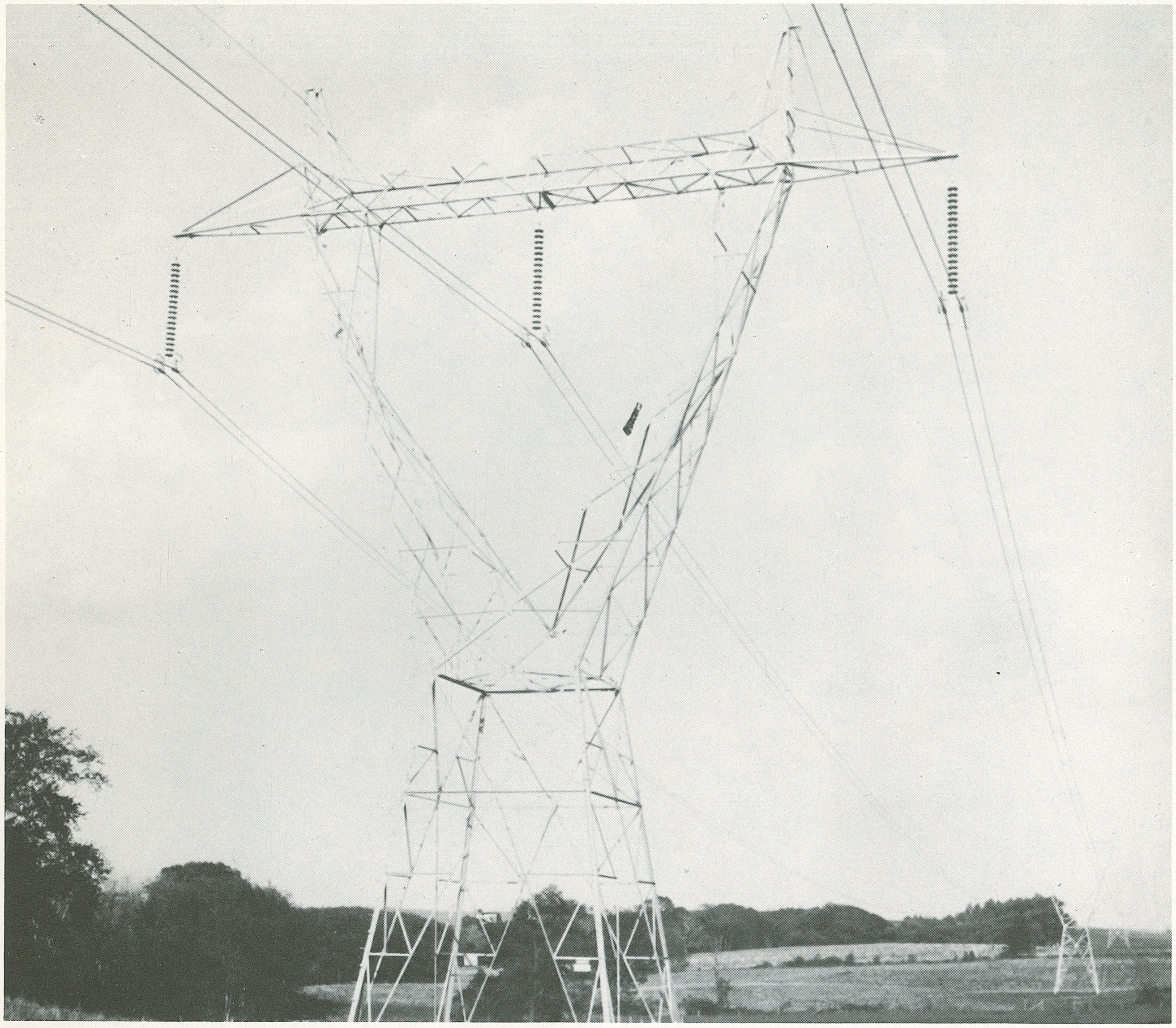
Timing

Because of the original nature of this work, it should be a continuous program of study over the planning stage of the 345-kv system. Three phases of study are suggested below:

Phase 1. (Late 1962) Agree on the scope of insulation to be included, the range of statistical variables to be included, and the source of statistical data.

Phase 2. (On completion of the first transient network analyzer tests and accumulation of other input data.) Perform calculations for a number of reasonable insulation design alternatives.

Phase 3. Refine the calculations for the final design alternatives, using the most accurate input attainable.



Optimum conductor diameter is determined by digital computer studies.

V. Economic Conductor Size and Radio Interference

Nature of the Problem

In planning the Kincaid 345-kv mine-mouth transmission system, Commonwealth Edison is faced with obtaining the maximum utilization of available rights-of-way. This, of course, calls for heavy circuit loadings and large conductor sizes. The larger conductors are attractive not only because of their greater thermal capability, but also due to their lower power and energy losses.

Of course, for over-all transmission economy, the value of the above gains must be weighed against the increased investment required for the larger conductor.

Methods of Solution

A computer program has been written which solves for the optimum conductor size of a given line, including consideration of:

1. Conductor configuration.
2. Foul weather corona loss levels and their coincidence with peak system load.
3. I^2R losses.
4. Line loading characteristics.
5. Line length.
6. Changes in tower costs as conductor size changes.
7. Energy costs, demand charges, RKVA charges, etc.
8. Series compensation and/or shunt reactance.

The results of this program show annual cost differential versus conductor area for pertinent assumptions in the above areas.

Objectives of Commonwealth Edison Studies

Upon agreement as to those economic factors that are pertinent to Commonwealth Edison, computer runs would be made to determine the optimum size of conductor for a range of circuit loadings. Single and multi-conductor bundles would be considered.

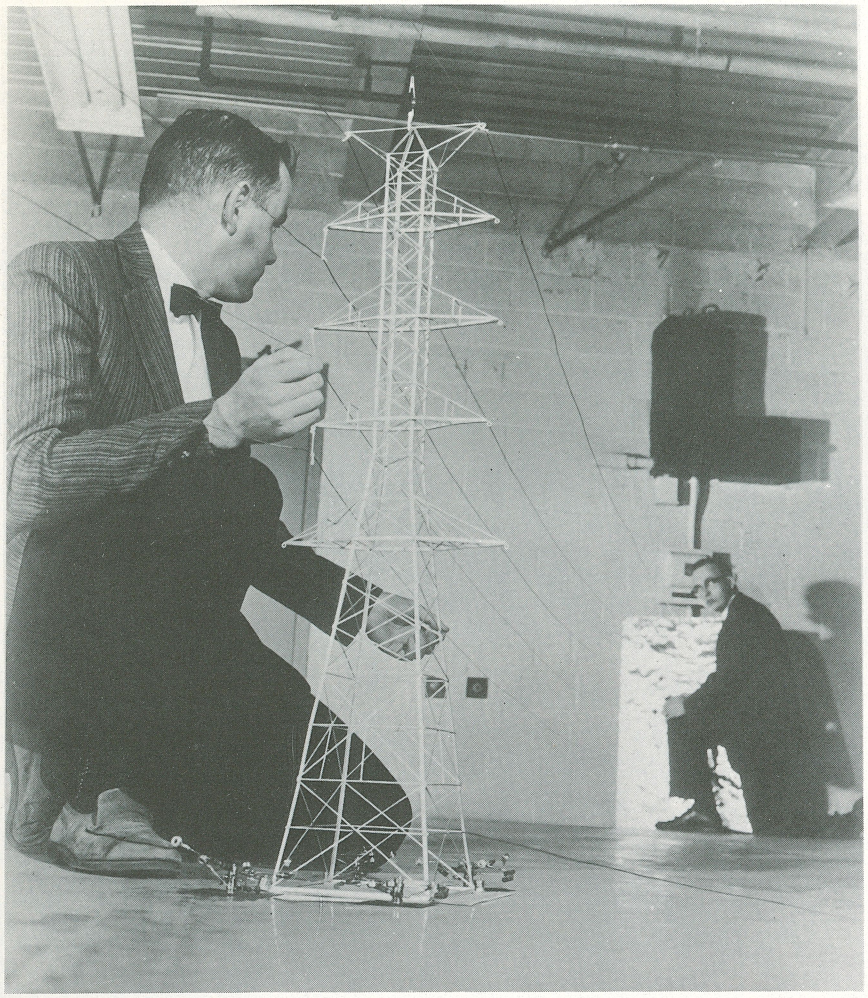
Interrelation with Other Studies

In some cases, corona loss and radio interference are important factors in determining the economic conductor size. However, for the heavy circuit loadings and the range of conductor sizes likely to be considered for the Kincaid lines, it is extremely doubtful that these factors will have an important bearing.

In the event Commonwealth Edison would wish to assess the merits of alternate designs from a radio noise standpoint, research data and computer programs developed in connection with Project EHV would be made available.

Timing

Since the results of this program have no direct bearing on the timing of other study proposals in this report, these studies can be performed any time convenient to Commonwealth Edison Company.



Model tower transient response is used to assure good lightning performance.

VI. Lightning Performance Design

Nature of the Problem:

An unusually high outage rate experienced on some recent 345 kv lines has given rise to renewed efforts at predicting the lightning performance of lines in the design stage. As a result of theoretical investigation into this problem, a calculation technique has been developed and applied to a number of new line designs.

Methods of Solution:

In the first phase of calculation, 50:1 miniature towers are constructed representing each of the major tower design alternatives. These towers are subjected to simulated lightning strokes to the ground wires at various points along the span and at the tower. Measurement of the voltages produced across the insulators give complete information as to the response of the line to lightning strokes.

Phase two of the calculation combines the results of Phase one and supplementary shielding failure data and then performs a Monte Carlo calculation to duplicate 10 to 30 years of thunderstorm experience, using lightning data applicable to the system under study.

The results of this calculation show total outages per year as a function of:

1. Isokeraunic level
2. Basic line design
3. Number of ground wires
4. Median footing resistance
5. Footing resistance distribution

Objectives of Commonwealth Edison Studies

Specific objectives of the Commonwealth Edison study would be to determine whether satisfactory lightning outage performance could be achieved without the use of two overhead ground wires and to establish the relative importance of footing resistance in the performance of each alternative.

Interrelation with Other Studies: Lightning outage calculations are not sensitive to the final design details of the structures being studies. This aspect of the tower design can be investigated as soon as the general tower type is known.

Timing

The lightning performance calculation would probably be done as soon as the general tower design is selected. In the meantime, data on footing resistance along the right-of-way might be sought for use in performance calculations.

Digital computers add powerful leverage in all ehv system design studies.

VII. Other Design Studies

While the foregoing sections list some prominent problem areas of EHV system design and their methods of solution, it is the purpose of this proposal to make available any other EHV information that will prove useful to Commonwealth Edison. Some specific areas of additional interest are:

1. A digital solution for 345-kv line reactance and susceptance. This program gives the complete impedance matrix, both in phase quantities and symmetrical component quantities. Results are useful in evaluating the effects of electromagnetic and electrostatic unbalance due to the omission of transpositions.
2. Analytical studies and laboratory tests relative to the elimination of fast rates of rise on waves entering 345-kv switching stations.
3. Analytical studies and laboratory tests relating to the suppression or localization of radio interference.
4. Analytical studies using matrix methods for the solution of radio frequency signals on overhead phase conductors or insulated ground wires.